CERTAIN SOCIAL ASPECTS OF INVENTION

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In studying the conditions under which inventions appear, perhaps three things most impress one: (1) the lack of any regular relation between the value of the invention to society and the degree of ability involved in making it; (2) the similarities in the motives of the inventors; (3) the wide differences in their training and their methods of attack and of work.

1. The social value of an invention shows little with regard to the genius required for it. There can be little question, for instance, that Watt's work with the complicated details of the steam engine involved not only greater technical knowledge of the laws of steam, iron, steel, etc., but also more complicated inductive and imaginative processes than such an invention as Gutenberg's of movable types. Movable types were only the last stage of a social process that had been going on for 250 years. As early as 1190 a German mill had been making paper out of linen rags, thus providing a much cheaper material than parchment for writing and engraving. This naturally gave a great stimulus to the reproduction of manuscripts, and in many instances plates were engraved of the entire page of a manuscript and as many copies made as desired. What Gutenberg did, therefore, in 1438, was to form the idea of engraving the single letters instead of the entire page, and of holding them together in some kind of frame while the print was being made. It seems a small thing to bring about the marvelous changes which followed, and we do not know whether Gutenberg himself foresaw its wider effects on civilization, though probably he did realize its immediate value in simplifying the labor involved in printing. It takes far less skill to engrave a single letter than to engrave a page of words, nor would it take long to learn the twenty-six letters of the alphabet, whether for the purpose of engraving them or of setting up copy. In spite of the relatively small amount of originality involved here, no one would question that the printing press has done at least as much for civilization as the stationary engine.

In this connection we think naturally also of the many instances of men who have made inventions and discoveries already made by others. There is no doubt that the spinner Hargreaves invented a spinning jenny in 1764 which spun twenty threads at once. He had as much inventive genius as Arkwright, if indeed he had not more, but he lacked the social outlook. The same holds of the sewing machine. The Frenchman Thimonnier not only invented but patented a sewing machine in France in 1830, before Howe had even begun to think of it, but the mob prejudice which threatened his life on account of it caused it to drop out of use and almost out of memory. In our own country Walter Hunt invented another sewing machine at least six years before Howe did, and sold his right in it to a Mr. Arrowsmith, but neither of them saw the social possibilities, a patent was not even applied for, and the model was relegated to the garret until Howe's success recalled this earlier invention to mind. We know that Bell has become rich and famous for inventing the telephone because his application for patent rights reached the patent office in Washington some twenty-four hours sooner than Gray's did.

Of such and many similar cases it is as trite to say that the unsuccessful man had as much ability as the successful, as it is superficial to depreciate the genius of the successful man because others have done the same thing. The interesting and important problem both for the psychologist and the sociologist is to ascertain if possible what other factors, whether individual or social, are involved which lead to the final success or failure, and how the waste of duplicating work can be avoided in the future. A knowledge of the lives of inventors and the conditions under which they lived should be at least suggestive, although it must be admittedly more or less defective in the details.

One group of inventions which shows the constant interaction between the individual inventors and social conditions is that concerned with making clothes, including the spinning jenny, cotton gin, power loom and sewing machine. If there were time and space doubtless we could carry these back to the dawn of civilization, but we will begin rather arbitrarily with Kay's invention of the flying shuttle in 1733. Before this a sort of equilibrium had been reached between the weaving and spinning processes. One spinner could hardly supply enough thread to keep one weaver busy, but this made the price of thread high enough to encourage spinners and discourage weavers, so that spinners increased enough in num-

bers to supply at least a fair amount to the weavers. Then came Kay and upset all this by his shuttle, which would send the thread through a warp of any width and do it twice as rapidly as before. The inevitable result followed. The weavers could do twice as much work, and wanted twice as much thread, but the spinners could not supply the thread for two reasons. In the first place they were working as fast as they could before, and in the second place, not many additional spinners could go to work because it was difficult to get more raw cotton. As a result the price of thread increased greatly, and the weavers were obliged to be idle one-half or one-third of their time. It is estimated that in 1760 in Lancashire, England, there were some 50,000 spinners and as many weavers as could find thread for their looms, but the looms stood idle much of the time, the price of thread remained high, and the need of relief was great.

Arkwright saw the need and, barber though he was, set about satisfying it in order thereby to make his own fortune. He was not the first to try to spin by machine, nor was he himself a machinist. Indeed we can not even affirm positively that he was ignorant of Wyatt's invention of 1733 or of Hargreaves' jenny of 1764. We are not even sure how much is owing to the machinist Kay whom he engaged to make his models for him. The most characteristic thing in his life is his clear realization of the need of more cotton thread and the gain to the man who could supply that need. In the invention itself, the most difficult part was to draw the cotton out to a thread by machine. Arkwright tells us that he finally got his idea from seeing red hot iron drawn out between two pairs of rollers, of which one pair revolved more rapidly than the other. So if cotton is put between rollers, the second pair revolving more rapidly than the first pulls it out into numerous threads. This was the central feature of the invention, though many details were added, to avoid breaking the threads, to twist them, to wind them onto spools, and so on. All this took up six years, from 1763 to 1769, in which Arkwright had spent all his money, had nearly starved himself and his wife (who finally left him), and had incurred the popular suspicion of being in league with the devil. In 1769 he took out his first patent and in 1775 a second on an improved model, but the jenny did not come into general use at once because he incurred the hostility both of the spinners and weavers. The spinners burned his mills when they could, because they believed that his invention would deprive them of work, and the cloth-makers organ-

ized against him and agreed not to buy his thread, because they thought he was making exorbitant profits. The long years of suit for infringements of his patent rights ended in 1784 by making the invention free, and the importation of raw cotton into England took a tremendous leap, rising between 1785 and 1790 from about 5,000,000 lbs. per annum to 25,000,000.

It is most interesting to notice however, that practically none of this came from our own southern states. In 1793, our total exports were only 187,000 lbs., and there was no prospect of an increase because we could for the most part only raise the short stapled cotton, which was very difficult to separate from its seeds. A smart negro woman could pick out one pound of cotton a day from the seeds, and would then have six pounds of seeds to the pound of fibre. Arkwright's spinning jenny therefore received checks in two directions and put the pressure on strongly in two places. It was limited by the amount of raw cotton which could be procured, and also by the rapidity with which the thread could be woven into cloth.

Let us shift the scene accordingly to Mrs. Nathanael Greene's Georgia plantation in the years just after the Revolution. At the end of the war our government was so poor that it paid the soldiers for the most part in grants of the new land west of the Appalachians and thus started the stream of migration which drained the eastern coast for years. Georgia, in common with the other southern states was losing its men, and it could offer no counter attractions strong enough to keep them at home. At that time the chief southern products were tobacco, rice, and indigo, and there were vast tracts which were not adapted to any of these, though they were suitable for the short stapled cotton. By 1790 the greatly increased English demand for raw cotton was widely known, but to southern patriots there seemed no prospect of our country benefiting by it because the short stapled cotton was so entangled with its seeds. This aggravating condition was the subject of much thought. It was under discussion at Mrs. Greene's one day by a party of gentlemen, who brought up the question of whether a machine could not be made that would separate the seeds from the cotton. Mrs. Greene exclaimed that if such a thing was possible she knew the man to do it, and she introduced Eli Whitney, a young Yale graduate who was tutoring her children to support himself while he studied law. Her enthusiasm was due to the fact that Eli was constantly mending and making things about the

plantation, some of them pieces of work requiring fine manipulation. He had grown up in a machine shop and was noted wherever he went as very skillful with his hands. Whitney had a long talk with these gentlemen about the profit to the South from such an invention, as well as to the inventor, and was so impressed by it that he got some unpicked cotton and began to experiment with it. He had to make various tools for himself, but in only a few months he had the central idea of the cotton gin in rough working order. The cotton was laid on an iron grating, something like a window screen but much coarser. Below this grating was a cylinder or roller set with projecting teeth in rows, like a coarse saw. When the roller was turned the teeth came through the holes in the grating, seized the cotton and tore it off from the seeds and down through the holes, the holes of course being smaller than the seeds. Whitney tried wooden points first, but found that they broke, and then the saw-like arrangement, but this was also defective and for some time he was puzzled, till one of the children brought him some stiff wire one day to make a bird cage, and he thought it was stiff enough to make teeth for the gin. When he first used this it worked so well that he called Mrs. Greene and others to see the triumph, but after a few revolutions the cylinder became so clogged with cotton that no more was torn off from above. Then, the story goes, Mrs. Greene seized a broom lying near and held it firmly against the roller as it turned, so that the cotton was brushed off, thus completing the invention. Whitney made this a permanent part by putting in a second roller covered with brushes, which revolved in front of the first and cleaned it as it filled with the cotton. This was the first cotton gin. It ran by hand, but it cleaned fifty pounds of cotton a day instead of one. Within a short time, however, Whitney enlarged it to be run by two horses, and to clean 500 lbs. a day, and later on it was run by water or steam power on a still larger scale.

The news of the wonderful invention spread far and wide. It went into use so rapidly that while in 1793 only 187,000 lbs. of cotton were exported, 1,600,000 were exported in 1794, a year later, 6,276,000 and in 1803, only ten years later, 40,000,000. Here, too, the inventor at once became involved in disputes over his patent. Many men succeeded in stealing the plans of the gin and making it for their own use. Whitney's factory was burned, and his patent right was defectively worded so that it was easy to evade. He could not even get witnesses to testify that his gin was in use in

Georgia, though in one case three were in operation so near the courthouse that the noise could be heard there distinctly. He brought suit after suit, nevertheless, spending there what money he received from other states, and finally after thirteen years of litigation he obtained a favorable decision, but was not able to get an extension of his patent right for a second term. Whitney himself therefore never made much money from his invention, and yet the judge who rendered the final decision said that the cotton gin had paid the debts of the South and trebled the value of her land. Surely this was a remarkable effect to come from four or five months of work.

Let us turn back now to the other check upon Arkwright's spinning jenny, that is, the inability of the weavers to use all the thread that could be spun. When the final decision was reached against Arkwright's patent letters, so that anyone could use the spinning jenny without paying for it, it became a burning question among business men whether to put up thread factories or not. A party who were dining together were discussing this one day in 1784, and reached the conclusion that thread factories would be risky investments, because weavers could use only a small part of the thread that could now be made. The clergyman of the town, Dr. Cartwright, who happened to be with the party, remarked that the only thing that would be satisfactory to every one concerned would be for Arkwright to invent a weaving machine that could go fast enough to use up all his yarn. This was very amusing to the manufacturers, who demonstrated to their own satisfaction how impossible it would be for a machine to make the movements necessary, in answer to which Dr. Cartwright could say nothing but that if a machine could play chess, like the one then on exhibition in London, another machine could certainly weave, which was a much simpler operation.

This conversation left such an impression on Dr. Cartwright's mind that he determined to try his hand at making such a machine, though it would have been hard to find anyone less fitted than he for such work. In the first place he came from a gentleman's family, in which work with the hands was considered degrading, and in boyhood he had never shown any liking for tools. In the second place, he had already acquired considerable reputation as a poet and writer, and had clearly before him affluence and reputation in those lines.

So ignorant was he of weaving that he had never seen a

loom in operation, nor did he desire to see one, but set to work *de novo*. He became more interested as he went on, engaged a mechanic to work out his ideas, and in the course of a year had a loom which he thought wonderful. He proceeded to take out a patent on it, and found to his intense mortification that his loom was not nearly so good as those already in use. Then he condescended to study what others had done, and set to work again. This time he worked for two years, and in 1787 he patented a loom in which the picking, shedding and beating up, formerly needing the hand, were done by machinery. This went considerably faster than other looms, though it needed one weaver to each loom, but its great defect was that if a thread broke the loom could not be stopped quickly, and so the cloth was likely to have holes and bunches. Cartwright worked in vain to remedy this, and not until 1841 was a device made by another man that was successful. Up to that time the hand loom competed with the power loom with considerable success, because its cloth was so much better in quality. About the time that Cartwright took out his second patent, other men took out a patent on a method of sizing, or stiffening the warp before it was put onto the loom. This made Cartwright's invention far more practical, because the warp was easier to handle and less likely to break. With this addition a child of fourteen could run two looms and weave three and a half times as fast as the hand weaver.

Cartwright met the same opposition as Arkwright. His mills too were burned by mobs, and his patents were infringed. He spent all his money in the invention, and finally went into bankruptcy and had to start life anew in his old age. In his case however, the Lancashire cloth manufacturers petitioned the Lords of the Treasury to reward him for his public services, and they gave him £10,000, which freed him from financial worries. His mind seems to have literally rioted in inventions in his later years, many of them useful ones, and it is interesting to know that he was one of the men who gave the most encouragement to Robert Fulton.

These three inventions therefore made cotton cloth cheaper than it had ever been in the history of the world, but the social pressure was only shifted to another place, viz., to the making of it into clothing. The abundance and cheapness of cloth naturally made everyone desirous of more clothing, but the amount of clothing was strictly limited by the rapidity with which sewing could be done by hand. The pressure was

felt in every kind of clothing but perhaps especially in the difficulty governments had in equipping their armies properly, both with clothing and with tents. In the seventy-five years preceding Howe's sewing machine patent of 1846, various patents had been taken out in France, England and our own country, for embroidering, quilting and knitting by machine, and we have already referred to Thimonnier's patent of 1830.

There is no evidence that Howe knew of Thimonnier's invention. He seems to have got his inspiration from a conversation which he overheard between his employer, a mechanician, and some men who had come to get his help in contriving a knitting machine. Mr. Davis examined their model but asked them why they bothered with a knitting machine when a sewing machine would be so much more profitable. They said that it would not be possible to make a sewing machine; to which he retorted that he could do it himself without half trying. The men told him he would become both rich and famous if he did, but apparently he did not care to, nor did Howe for several years, though he did think about the possibility of it. He was then a boy of 18 or 19, poor and sickly. When 21 he married, and both his sickliness and poverty increased steadily, so that he was incompetent in his work and wretched. In very desperation to relieve his poverty he began in 1843 to experiment seriously on a model for a sewing machine. At first he assumed that the needle in the machine must make much the same movements as when held in the hand, and he seems to have spent something like a year in fruitless attempts to imitate the hand movement, although he did alter the needle, experimenting with a needle that had two points and the eye in the middle, and trying to invent a device that would push the needle back and forth through the cloth. At length he asked himself why he should try to get a stitch like the hand stitch? The necessary thing was only to hold the two pieces of cloth together firmly. After he had thus freed himself from too close imitation he progressed rapidly, so that in a few months he had the idea of the lock-stitch worked out on his rough model. In the lock stitch the eye of the needle is as close as possible to the point, so that when the point is pushed through the cloth the thread is carried through and makes a loop on the lower side. A shuttle carrying thread is then thrown through this loop, the loop is drawn tight and the first stitch is made complete.

This first wood and wire machine however, was far from being good enough to convince others of its commercial value,

but Howe was so sure of ultimate success that he gave up his position and took his family to live first with his father and then with Mr. George Fisher, who believed in the machine enough to become his partner, and who was willing therefore to support Howe's family and advance him money. About six months later his model was good enough so that he sewed his first seam on the machine, and a few weeks later, in May of 1845, he sewed two suits of clothes on it, one for his partner and the other for himself. This first model was a very little thing that would fit into a box with a cubic capacity of only one and one-half feet. It was turned by hand, but it sewed 250 stitches a minute, about seven times as fast as the most rapid seamstress, and we all know how much firmer the machine stitch is than the hand stitch.

Howe tried in vain to get a tailor to exhibit the machine in Boston but finally did it himself, sewing anything brought to him and racing with any tailors or seamstresses who were willing to do so. Still no orders for the machine came in. One reason for this was that it cost $300, a price so high that it could only be used in large tailoring establishments, but other reasons were the belief that it could only sew straight seams, and that it would deprive tailors and seamstresses of work. In September, 1846, he took out the patent on his machine, and for another year struggled on against indifference and ever increasing poverty. Then as a last desperate venture his father bought a steerage ticket to London for Elias's brother Amasa, in order that he might try to interest some wealthy man there. Amasa succeeded in rousing the interest, but unfortunately the corset-maker in question was willing to take advantage of his dire poverty and his inexperience, and for £250 he bought the right to take out the English patent, to own the model Amasa had brought with him, and to make and sell as many as he pleased. He agreed to pay Elias £3 on every machine sold in England but never did so, though he made for himself a fortune of over $1,000,000. Then he persuaded Elias to come over in order to adapt the machine to corset-making, but after he, with his wife and three children was settled in London, there was constant fault-finding and finally a break. Elias was discharged and left practically penniless in a strange land. The family nearly starved to death literally, and at length Howe borrowed money to send them home in the steerage, while he stayed on to finish his third model. His own situation became more desperate all the time, however, and at length only by pawning his patent letters was he able to get money

to buy himself another steerage ticket to New York. He landed in this country with twenty cents, and his biographers tell us, as weak from lack of food as if he had had a severe illness. Within a week he received news that his wife was dying in Cambridge, but he was unable to go until his father sent him enough money to pay for his ticket, and in order to attend her funeral he had to borrow a suit of clothes.

Now, as with other inventors, he found that the sewing machine was coming into favor in this country. Other men had also made machines, and though there is little evidence that they copied from Howe, they did in most cases infringe his patent. He tried at first to negotiate with them privately, after recovering his patent letters from the pawnshop by means of borrowed money, but under the leadership of Isaac Singer they refused to treat with him, and he either had to bring suit or lose all benefit from the invention. His father again came to his aid, mortgaging his farm this time, for $2,000. In the course of three years the matter was decisively settled in Howe's favor, and when his first patent expired he was able to renew it for an additional seven years, so that at its expiration the machine had earned for him about $1,700,000.

The modifications of the machine are almost infinite. Between 1842 and 1895, patents to the number of 7,430 were taken out on various accessories. It is used not only for sewing cloth, but also shoes, harness, corsets, rubber hose, belting, etc. It is now run usually by steam, and instead of 250 stitches per minutes can sew 900. In some instances a considerable number of needles (two to twelve) is fastened to one machine so that several seams can be sewed at once.

These four inventors show in a very interesting fashion the possible individual variations in invention, together with the interdependence of inventions and general social conditions, and the combination of motives which influence each individual. All four had a strong conviction of the social value of their inventions but the other personal factors were very different. Arkwright saw the future of the spinning jenny, and the wealth to be realized from it, but the extent of his mechanical genius is a question. He had instead the power of choosing and controlling men, which not only procured for him the first use of the invention but later on enabled him to organize his factories so well as to become wealthy in spite of the loss of his lawsuits. From the available data one is inclined to think that he was far more the able administrator than the inventive genius. The spirit of

two men could hardly vary more than did his and Cartwright's. The latter's chief, if not sole motive, was to demonstrate the possibilities in a machine, although he realized also what its value would be to society. He had, however, no such personal ambition as Arkwright, and was more likely to lose in social position as well as wealth than to gain by going into such mechanical work. It is difficult to understand just why he should have taken up the task of making a loom with such ardor, when he had never before shown any aptitude for tools, but the outcome seems to show beyond doubt that he had very unusual inventive genius. His first crude loom is itself a remarkable achievement for a man who had never seen one, and the variety of his other inventions, many of which he gave freely to other men instead of patenting them himself, shows his breadth of imagination. In Whitney and Howe, on the other hand, especially Whitney, we get men who grew up in the machine shop, but while Whitney had a great deal of administrative ability, Howe was so hampered by his feeble health with its consequences of inefficiency and self distrust that it was difficult for him to convince others of the value of his invention. It would be very interesting to see how far these men conform to Adler's theory of organic *Minderwertigkeit,* but it can not be attempted here. All save Cartwright assuredly had the sense of poverty and social inferiority, while Howe had in addition a very weakly constitution.

Another chapter that would be well worth while psychologically would be a study of the motives that led manufacturers to the attempts to infringe the patents on the one side, and the obstinacy of all four of these inventors in fighting such infringements on the other side. This however might well be extended to all inventions. So notorious is such infringement that we are told (in a recent number of "Science") that Edward Weston protected himself by not taking out a patent on a given device until he had an improvement on it so far along that he could take out a patent on that also within a short time, and thus balk the numerous manufacturers who always take advantage of the description required in the application for a patent. Manufacturers on the other hand, are so well aware of the possibilities of stealing inventions, that if one of their men invents a device they often prefer not to take out a patent but to have the machines made secretly in their own factory and keep them under lock and key, paying the men who use them liberally enough to secure their loyalty. Nor do they scruple to send their own employes

into the factories of others to pick up what they can in the way of new devices. It is not uncommon for them to make a contract which gives them the right to all of a man's inventions for a term of years.

It is not difficult to understand the feelings on both sides in the matter. The inventor naturally enough feels that he himself has created the machine, and has the first right to whatever it can earn. In some cases, as with Howe and Morse, who underwent great privations in the course of their work, most of us must feel that no amount of money can be an adequate compensation. The inventor who has had to endure for years the distrust and criticism of friends and perhaps of his own family, to say nothing of poverty, naturally feels that he has a right later on to any kind of compensation he can get, although nothing can really heal the wounds made by the ridicule and scorn of his social world.

On the other hand the manufacturers have considerable reason for feeling that it is more or less accidental that this or that individual was the first to make or at least the first to *patent* a given machine or device, and that the rewards for the invention are often all out of proportion to the work and talent involved. Whitney, e. g., worked only a few months on the gin and spent very little money, but in introducing the gin through the South he took one pound out of every three cleaned by way of payment. In the contract made with the state of North Carolina it agreed to pay him two shillings and six pence a year for every saw used in the state. That is, Whitney would not sell a single machine, but would only allow the use of them under strict conditions of supervision, which irritated the planters and inclined them to take any possible advantage of him. Not only that, but the planters were poor men as a rule, and probably felt that their need was made the occasion for extortion.

Again, in Whitney's case no one could question that he had made the invention, but in Arkwright's the fact that he was unable to make his own models almost inevitably throws doubt on his inventive ability. In the actual process of invention the relation between manipulation and originality is so close, the chance of an accidental, unforeseen success or failure in combining the various parts of the machine or the various materials used is so great, that it is small wonder Arkwright's competitors questioned whether he or his machinist or Hargreaves should have the credit. Again, we have shown repeatedly that various men have made the same invention, or that the final step to be taken was a very small one.

Howe simply happened to be fortunate in taking out the first American patent, as did Bell. Everyone knows that Wallace formulated the same theory as to the origin of species as did Darwin, and that both got the germ of their idea from Malthus. The one factor in each case which gives one man sufficient advantage over others so that he gets most of the fame and the money for the invention seems more often than not to be entirely unrelated to the genius or talent necessary. In Arkwright's case it was his rather bullying disposition and his administrative ability, though his patent letters were so defective that he finally lost his lawsuits. In Howe's, on the other hand, it was solely due to the fact that he took out his patent as soon as possible, while he seems to have been totally lacking in the ability to impress and manage men so conspicuous in his most prominent opponent, Isaac Singer. Whitney finally made his fortune in the totally different line of gun-making, after spending most of the money that came in from the gin in lawsuits; while Cartwright again, after similarly spending his fortune on lawsuits lived on a government pension and gave away many of the later devices which might have made him wealthy. These men seem to have secured recognition and to have been motivated by their sense of the social value of the invention, though this was not sufficient to secure wealth to all of them.

But again, if we had access to the inner history of factories, there is no doubt that we should find that many workmen make devices or inventions which have far-reaching effects on the industry without themselves foreseeing the effects. The short cut appears in the course of working with the machine, and the workman may use it himself for weeks or months before the foreman or manufacturer notices it. Then only too frequently the manufacturer adopts the device either without giving the workman any credit or money payment, or giving him a sum very small in proportion to the saving of money or labor made by the device. So we have on the one side factories offering rewards of small sums for inventions, and on the other side workmen refusing to think or plan, or concealing their improved methods, or when they are shrewd enough carrying them to a competing firm to sell.

It would appear therefore, that while the actual attainment of fame and fortune depends upon the social insight of the inventor impelling him to take out patents, and while in many instances the value to society and the desire to improve his own position and fortune are the motivating factors, the mechanical ability or inventive process itself goes on in many

other cases without any apparent relation to society, but more as a by-product of the interaction between the workman and his machine.

Rignano in his lucid series of articles has restated the point made by several others that scientific generalization rests in the end upon the possibility of repeating the experiments on which the theory rests, that is, in repeating the sensations and perceptions, so that all normal persons may get the same experience. In proportion as we depart from experiment and proceed to inference and induction we enter debatable ground, for it is increasingly difficult to keep clearly in mind all the data and particulars involved. Nevertheless, the history of science, and especially of mathematical science, which Rignano discusses in his latest article, shows that even the most abstract ideas, imaginary numbers, and the like, though they may be symbols of symbols, run back to a physical reality, to a perceptual experience, including in this the kinesthetic factors and particularly those involved in manipulation.

Granted such a basis of sensation and perception, the part which they play in any creative thought process becomes a highly important problem. To what degree can a man carry on synthetic thought without recourse to perception? What part is played by the process of writing or speaking as contributing perceptual factors? Is the new combination more likely to be attained first in thought or in a seemingly accidental combination of perceptions? In invention we see as clearly as anywhere else, perhaps, the close relation between the perceptual experience and the concept or theory or abstract truth, but also the wide variations possible in the proportions of each. In his *Psychology of Efficiency* Rutgers has analyzed human methods of meeting new situations which involve motor processes. His material consisted of mechanical puzzles, usually of wire, in three dimensions. In order to solve the puzzle some part had to be removed thus necessitating manipulation as well as thought. In his twenty-seven subjects he found that the methods of solution ranged from the animal hit-and-miss method to the forming of a working hypothesis before the puzzle was touched, but in general in proportion as the problem was new the hit-and-miss method was approximated. These extremes remained in some cases even when the puzzle was learned. That is, some subjects, even when they could do it perfectly seemed unable to follow a plan, but did it as it were automatically, while others could describe each step in detail before doing it. When the subject took the puzzle and began to handle it, his movements were

to large degree random, and he might chance upon the one which solved the puzzle. His future success then depended upon the degree to which he could recall and attend to the movements made, and see their relation to the puzzle. Not infrequently memory was illusory, or a false hypothesis had been formed which prevented the subject from experimenting freely and hindered the solution. In the actual solving, there was a complicated interaction between random movements and attention to them. Sometimes the movement was accidental but the subject saw just as he made the movement that it would be successful; in other cases he could remember it well enough to succeed at once the next time. As a rule however the first accidental success served only to localize the point of attack, and further experimenting about this focus was necessary. Rutgers, like Book, emphasizes certain points in the learning. The first success with the puzzles, like the first short cut in typewriting, is likely to be accidental, but it is also likely to come only when the subject is in the best physical condition and is attending most closely. Then it is likely to be done more or less unconsciously for a time, but gradually to be perceived and be brought under volitional control. Book then goes into further detail in the study of acquiring skill in typewriting. After the first rapid stage of learning, the subject reaches the point of average attainment when it is very much harder to acquire a greater degree of rapidity or correctness, partly because the material has become familiar and so less interesting, and partly because few persons have had any experience in making the higher groupings. The learner tends to become lazy and remain at the same level, or on the other hand he tries to proceed too rapidly, and so fails in correctness as he progresses. To work at the optimum but not to go beyond it or fall below it is the important problem for each individual, and this again is a matter of wise control of attention. Nevertheless, Book emphasizes again and again, that the most effective control of attention is not obtained by direct means, but only by keeping in the best physical condition and by having the keenest interest in the work and the highest incentive to keep at it. He who says, "Go to, to-day I will acquire this or that definite degree of skill," is almost sure to require either too much or too little of himself. The psycho-physical organism is too complex for us to forecast its possibilities at a given time as yet.

This holds to an even greater degree of inventions. While it is generally true that the workman in a given trade is more likely to invent than one who knows nothing of the industry

in question, it is not essential. Even in a trade so technical as engineering Kent reports that of the 72 talented American engineers whom he studied 16% had not come into contact with machinery in boyhood and 17% reported that they had no especial mechanical interests in boyhood. On the other hand Kent says that in all the cases of which he knows, a boy who has made an engine before he is seventeen years old has later atttained eminence. That is, the early presence of mechanical interest and skill enables us to prophecy positively, but its absence does not make it safe to prophecy negatively, for it may be compensated later by unusual motivations and application.

Let us take up in more detail a specific invention, that of Watt, to see if possible how accidental manipulations or chance associations interact with the end in view and the working hypothesis. Watt is one of the engineers who showed his taste from boyhood. Adler would probably consider him an excellent case of compensation for organic inferiority. He was a sickly boy, unable to share the active sports of other boys, so that he was forced to amuse himself to large degree. He naturally enough imitated his father's work in his shop, and when fourteen years old he set up a forge for himself. His father sold instruments and also had a carpenter shop and the boy learned to use the various nautical and other instruments on sale or left for repairs. When eighteen years old he determined to be a maker of scientific instruments, and went to London and later to Glasgow to learn the trade. After various difficulties with the guild, because he did not wish to spend the required number of years as an apprentice, the University of Glasgow in 1757 gave him the use of a room and a half official connection with it. Here he made all sorts of mathematical and musical instruments, taking a partner later, and building a flourishing business.

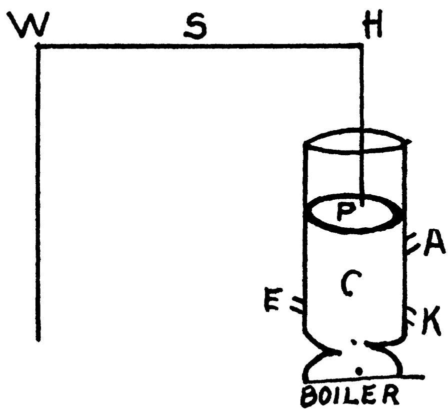
To understand the conditions under which Watt worked something must be said of certain other discoveries upon which the invention of a steam engine depended. Even the Greeks and Romans knew something of the power of steam, and later it was used to a small extent for melting ores, and for turning the spit. In 1663 the Marquis of Worcester described a pump to be run by steam to pump the water out of mines, but could not make his idea practical. Only thirty years later however, the Frenchman Papin discovered that if water is boiled in an air-tight vessel until it all turns to steam, and if the steam is then condensed by sudden cooling, a vacuum will be left in the vessel. Of course no vacuum

is perfect, but in Papin's the difference between the atmospheric pressure and that of the so-called vacuum was great enough to make a crude steam pump practicable, and Savery made this use of the vacuum eight years after Papin's discovery. The principle involved is very simple. There is a large steam vessel, the precursor of the engine cylinder, set over the boiler, with an opening between the two so that the cylinder fills with steam as the water in the boiler boils. The cylinder has three other openings: (1) There is a pipe leading down to the water in the mine, which is to be pumped out; (2) Another pipe leading to discharge the water after it has been drawn up, and (3) a third pipe by which the air is forced out of the cylinder. At first the water and discharge pipes are closed and the cylinder is filled with steam which forces out all the air. The steam is then condensed, and the water pipe opened. Since the pressure within the cylinder is much less than that outside it, the water is forced up into it till the pressures are equal. The water pipe is then closed, the cylinder again filled with steam and the discharge pipe opened and the mingled water and steam discharged.

This however was greatly improved by the Englishman Newcomen, who had a very pressing problem before him. In England the need of power for pumping the water out of the copper mines had become acute. The mines were extremely valuable, but they had been worked for a long time and had become so deep that the enormous suction pumps run by horses would no longer pump out the water. Many had been abandoned although the copper was by no means exhausted and additional ones were being closed all the time. Newcomen formed the idea of using Savery's pump with improvements. In the first place he wanted to use the pumps already in the mines, but to have a greater power attached where the horses had been before. That is, he wished to make steam work the handle of the pump up and down.

This necessitated a number of changes which can only be indicated here in the rough diagram. From W a chain runs down to the pump in the mine, and HW is a beam hung on a socket at S. From H a rod runs down to the piston P, which is essentially a smooth sliding cover to the cylinder, C. When the steam is forced up into C, the air is driven out through A as in Savery's engine and when the cylinder is full of steam the boiler is shut off from it, and the steam is condensed by a spray of water running in from E, the water being run off from the cylinder through K, leaving the vacuum in C. Then the pressure of the air outside the

piston forces the piston down at once, and with it the beam, which thus begins to work the pump at the other end. When the piston reaches the bottom of the cylinder it is drawn up to the top and the process begins over again. Newcomen's engine was improved by Smeaton, and for nearly a century it was used commonly in mines. But only 10% of the power was available for the pump, the rest being wasted in various ways. The piston made not more than three or four strokes per minute, and moved about fifty feet per minute, and the engine consumed twenty-eight pounds of coal to each horse power produced, though to-day but one and one-third pounds are needed per horse power. Wasteful though the Newcomen



engine was, it had considerable sale among mine owners because it was the only source of sufficient power to remove the water from the mines.

By 1760 however, it was failing to do even this in some instances, and when young Watt discussed steam with his friends we can not doubt that the deficiencies of the Newcomen engine and the practical need of more power were frequently touched upon. In any event, shortly before 1763 Watt learned that the University had a Newcomen model which had been sent to London to be repaired, and he put in a request that he be allowed to get it back and try his hand at it. This was granted and after a long delay the model reached his workshop. We can reconstruct to some small degree at least, the effect it had upon him. He was a maker of mathematical instruments and that means that he had a great love of exactness combined with remarkable deftness. From childhood he had taken his toys to pieces and not only

put them together again but often had combined the parts in new ways. When he got his forge in his fourteenth year, he made miniature cranes, pulleys, pumps, and so on, and out of a silver coin he made a punch ladle, still preserved. He also mended the various nautical instruments brought to his father, such as compasses and quadrants. Later when established in his rooms at the University of Glasgow, while waiting for a better class of work to come, he made musical instruments, and constructed a barrel organ for the first time, while in the second one that he made he added a number of improvements. He said of himself that he was always dissatisfied with others' work as well as with his own. It is easy to see how so wasteful a machine as the Newcomen engine would irritate a mind of this type, and almost inevitably lead him not only to mend the model given him but to experiment with it to prevent so much waste. Further, in 1759, when Watt was only twenty-three years old, his friend Robison, with whom he was continually making experiments and having discussions, suggested to him that steam might be used to drive carriages and Watt began to make a model of a steam engine, but was not very successful and laid it aside when Robison left Glasgow. Discussions with another friend, Dr. Black, however, kept the idea of steam power alive in Watt's mind, so that when he learned of the Newcomen model he made the request already noted. While waiting for it he experimented on a very small scale with the force of steam, using Papin's digester, and for cylinder an ordinary syringe only one-third of an inch in diameter, with a solid piston and stop-cocks put in to admit or shut off the steam. Tiny and crude though this apparatus was, he learned from it the expansive force of the steam upon the piston, and also the greatly increased elasticity and power of steam kept under high pressure. He saw the mechanical possibilities of this at once, but he could not make actual use of them because he could not get workmen skillful enough to make boilers that would be safe. When the Newcomen model finally arrived and was set up, as he supposed in perfect condition, after only a few strokes of the piston it stopped and would not begin again, though the fire was made as hot as possible and as much steam as possible produced. This was a challenge not to be refused. During the next year Watt and Robison tried various devices, in the course of which Watt stumbled upon the fact of latent heat, which his friend Dr. Black had already discovered and explained the theory of to him. Watt found that steam would heat six times its weight of water

from freezing point to boiling point, its own temperature. About the same time that he was making these experiments (his own accounts and Dr. Robison's, written some twenty years afterwards, do not give us the exact order of events, and differ in some instances with each other), he was also experimenting on both the boiler and the cylinder of the engine. The knowledge of the latent heat in steam made it very important not to waste any steam, and also to increase the heating surface of the boiler as much as possible in order to produce the greatest amount of steam from the smallest amount of coal. Accordingly he ran flues through the boiler, or built the boiler about the fire, made it of non-conducting materials, and so on. By degrees however he became convinced that the greatest waste was in the cylinder, and that in his small models the wastes were greater than they should have been according to the text book accounts. Particularly he found that too much steam was condensed in the cylinder, and that when he tried to condense it more rapidly by injecting more water, too much steam proportionately was wasted. After trying this out repeatedly, he found that water in a vacuum boils at lower temperatures than under usual atmospheric pressure and so he got steam and pressures which he was not expecting. In all this he was using a very small scale of models. Sometimes his cylinder would have a diameter of six inches and a stroke of twelve, or sometimes it would be only an apothecary's syringe, and a flask that would hold a pound of water. Again, a tea kettle would serve as his boiler. But by means of such crude and small apparatus, by the fall of 1764 Watt had reached certain conclusions. He was confident that the chief waste in the Newcomen engine came in cooling the cylinder. We have already noted that to get a vacuum in the cylinder, the air is first driven out by steam, and then the steam is suddenly condensed from 212° to about 100° by the injection of a stream of water. This of course also cools the cylinder, and when the steam is let in next time Watt found that from three-fourths to four-fifths of it condensed on the cold walls of the cylinder before any could be used in work. How was this waste to be prevented? Naturally, if the walls of the cylinder could be kept as hot as the steam, the steam would not be wasted in heating them. But how could the steam be condensed without cooling the cylinder? To cool the steam in the cylinder from 212° to 100° without cooling the walls of the cylinder at all was therefore the crucial problem in the invention of the modern steam engine.

Several months passed of which we know little. In the summer before Watt had married, and during this fall he was attending diligently to his proper business of instrument making, as well as his experiments with the engine models. In the following spring, probably in April of 1765, he went for a walk one Sunday afternoon on the Glasgow Green, and between the unromantic buildings called the wash-house, where the Glasgow washerwomen did their weekly rubbing, and the herd-house, the great idea flashed into his mind. We know no more of the details than that he had been thinking as usual of his engine. This central idea was that, to use Watt's own words, "as steam was an elastic body it would rush into a vacuum and if a communication were opened between the cylinder and an exhausted vessel, it would rush into it and might there be condensed without cooling the cylinder." It would then be necessary to draw off the condensed steam and the injection water from the condenser, but this could be done by a pump. He concludes, "I had not got farther than the golf-house when the whole thing was arranged in my mind." We might say carelessly that now the invention was made, but Watt still had four years of disappointment ahead of him before he could even take out his first patent, and ten or twelve before he began to get any financial returns. Watt was twenty-nine at this time.

In his own account, written thirty-one years later for his attorneys, he says that if he had been content merely to make the engine on this plan, thus saving the steam and fuel, he might have put it on the market very soon, but he wanted to make the cost less as well, and he very soon had in mind other devices which he believed would improve the engine more than they actually did. He says that his inexperience in "mechanics in the great" led him astray.

The next step was to see whether the idea would actually work. The next day Watt obtained a large brass syringe, 1¾ inches only in diameter and 10 inches long and put a tin top and bottom onto it to make it into his cylinder. The condenser consisted of two tin pipes only about 1/6 inches in diameter and 10 inches long, standing upright and joined at the bottom to the pump and all placed in a vessel full of cold water. A pipe, of course, ran from the condenser to the cylinder. In the piston rod he also bored a hole through which the water condensing when the cylinder was first heated could come, and when steam began to come out through it and through the condenser valve it was supposed the cylinder was full of steam. The valves were then shut and the vacuum

was made in the condenser by means of the pump, so that the steam rushed in from the cylinder. The piston of the cylinder at once rose in its turn, raising with it a weight of 18 lbs. attached to its rod. (The diameter of the piston was 1¾ inches.) The amount of steam used and the weights lifted were carefully noted.

At first, after the piston had risen it was allowed to fall by the atmospheric pressure on its top, when the vacuum was made in the cylinder below, but Watt realized very soon that the air going down the sides of the cylinder also cooled it (the old cylinder being open at top and air usually being only 70°-80°), and that it would be very desirable to close the cylinder at the top and have two pipes at top and two at bottom, to bring in and carry off the steam above and below the piston, pushing it down as well as driving it up by the steam pressure. The engine thus became a true steam engine as distinct from Newcomen's atmospheric engine and the piston a double-acting one. Thus a further saving of heat was effected. This modification seems to have been made even in the first tiny model, and in the larger one which Watt at once made there was also an outer case to surround the cylinder and be filled with steam, in order to keep its heat still more uniform.

Now Watt entered upon what was perhaps the most trying period in his inventing. He himself, as we have noted, was a maker of scientific instruments, with all the exactness of mind and skill of hand which that necessitates. The success of his engine depended entirely upon the presence of those qualities in the workmen who were to make its various parts, especially the cylinder and piston, but he could find no such workmen in the United Kingdom. The larger model which Watt himself made with the aid of a mechanic was good enough to *promise* great things, but the cylinder was imperfect so that the steam escaped at many places and the piston was far from air tight. The same was true of the still larger one which he built a little later, and also of those tried after he went into partnership with Roebuck. The difficulties with the imperfect shape of the cylinder, it should be said, were never overcome until years later when Mr. Boulton found the iron-master John Wilkinson. As long as the cylinder was imperfect the piston could only be relatively tight in it, though Watt did improve this to a considerable degree by the arrangements of collars which he put around the piston, the use of greases and oils, etc., with all of which he seems to have tried almost everything imaginable. From 1765 till

1770 he could not give as much time to the engine as he wished, but took up surveying as a business, and also made minor inventions along other lines. In 1767 he became acquainted with his future partner, Mr. Boulton. Mr. Boulton was the owner of the most famous metal works in England, and for some years he had been greatly interested in the possibility of using steam power in his factories, since he had not sufficient water power for the growing industry. He and Watt had for three years interchanged letters, and debated the possibility of a partnership, but Watt was already bound to Dr. Roebuck so that Mr. Boulton could not enter on the terms that he wanted. In 1770 Mr. Boulton asked Watt to send plans for an engine, which he would try to make at his works. This was done but the engine was no better than the others, though Boulton had the best mechanics in England working for him. Other attempts about the same time with older models, were equally failures and Watt began to think that his engine would never be a commercial success because he could not get skilled workmen to make it. Four years more passed in earning a living, suffering from ill health, and failing in his attempts to improve the engine, but in May of 1774, an agreement was finally reached with Boulton and Watt betook himself and his models to Birmingham. He had taken out a patent in the spring of 1769, but he had not as yet made a single engine for sale, although he had spent several thousand pounds in experiments besides all his labor.

At Soho Boulton's workmen set up the model over which Watt had worked so long at Roebuck's, and this time it worked better than ever before, though still open to much improvement. Boulton also began to get inquiries as to the nature of the engine, whether it could be used for mines, etc., and other men began to steal the plans of the engine or to invent on their own account. All this showed the demand and the financial gain to be made if the patent rights were protected. Boulton accordingly persuaded Watt of the necessity of getting an extension of time on his patent and after some trouble this was secured in the winter of 1775, for twenty-four years.

We should note at this point the invention of John Wilkerson, the iron founder, who introduced a new boring machine to make the large cylinders necessary for cannon and steam engines more accurate. The usual method at that time was to have the rough shape of the cylinder cast solid, and afterwards to bore the size wanted, but there was nothing to guide the borer, and so the hole was not likely to be perfectly straight. Wilkinson however, steadied the borer by a very

strong iron rod, along which the borer slid, so that whatever the shape given in the casting, the hole bored was perfectly straight and round. Nevertheless, when the first engine was made at Soho, Smeaton, perhaps at that time the most famous engineer in England, did not believe it would ever be practical on account of the difficulty of getting the various parts accurately enough made, although he fully recognized its superiority over other forms if this could be done.

Nevertheless Boulton and Watt began to sell engines, guaranteeing that their engines would do as much work as the ordinary engine, for half the expense in fuel, and in March, 1776, Boulton wrote that if they had a hundred small engines and twenty large ones on hand they could easily sell them all. He hoped to make one engine every two or three weeks, or from twelve to fifteen reciprocating and fifty rotative engines per annum. While Boulton managed the business end, Watt was occupied in making improvements and in setting up those sold. He was constantly trying new materials for collars or lubricants to the cylinder, changing the form of the condenser so that it would cool the steam more rapidly, changing the position of the valves and making them tighter, and so on. In one of the first engines made at Soho we are told that it made 500 strokes with 2 cwt. of coals, while a month later it made 2,000 strokes with 1 cwt.

For some years Watt spent most of his days setting up engines, and from 1780 to 1785 he took out five patents on different inventions: a new method of copying letters, a machine for drying linen and muslin by steam; the very important one on methods of applying the power of steam engines to produce a rotary motion around an axis, which made steam applicable to all mill machinery; an additional patent on the steam engine itself. In this last are specified the important principles of using the expansive power of steam, the double-acting piston, the double engine, a toothed rack and sector to guide the piston movement, and a rotative engine or steam wheel. Both the expansive power and the double-acting piston had been known to Watt from about 1767 but he had not used them on account of the difficulties involved in making them. Finally, Watt patented methods of converting circular or angular motion into perpendicular, along with many minor improvements, and a device by which the steam engine would work a tilt hammer, of which combination he writes with great pride in 1783 that the engine had a cylinder of 42 inches diameter, and a stroke of 6 feet, making as much as 50-60 strokes per minute. It would work a

hammer of $7\frac{1}{2}$ cwt., raised 2 feet high, which could be made to strike 300 blows per minute.[1]

Boulton and Watt got their profits from their engines in the saving made over the common ones, that is, one-third the saving of fuel to be paid either annually or semi-annually. They found so much tendency among the men to steal the coal and to deceive them, that Watt set to work upon a counter, which should record the number of strokes made by the engine and thus enable them to calculate the amount of steam made and coal burned. Among other improvements were those of the throttle valve, governor, steam gauge, indicator, and smoke consumer, which also burned the fuel more completely.

During these years of invention, as before, Watt suffered a great deal from ill health, severe headaches, and low spirits. He speaks of his health being so bad that he fears he can not hold out much longer, he longs for a rest for his weary bones and laments the loss of the inventing power, although it was really as active as ever.

As to the inventive process itself the reader of his biographies is most impressed by the fact that the actual making of an engine valuable for practical purposes lagged so far behind the successful model. The theory was well worked out and the skill in making small models was acquired by Watt ten years before a large working engine could be turned out. Watt himself never seems to have set about acquiring the skill necessary for casting perfect cylinders, nor to have turned his inventive ability upon that problem. This is rather strange, for as far as we can judge from his letters he realized that the difficulty lay in getting a perfect cylinder. Or perhaps we should say that he realized that the difficulty lay in getting the piston perfectly tight in the cylinder, and thought that he might accomplish this by means of his cóllars and lubricants. At any rate he seems to have expended his energy in that way and to have used the hit-or-miss method to the extreme there. In trying out different shapes for the condenser and boiler, the part played by theory was more important, for he wished to get as much surface as possible for the water or the fire to play over.

It is an interesting question whether, if Watt had not found Boulton and Wilkinson, who took charge of the busi-

[1] To-day a piston travels only at moderate speed when going 1,000 feet per minute in a cylinder three feet long, and makes 166 revolutions. It costs about eight cents to get one horse-power for twenty-four hours.

ness management and of the actual making of the large cylinders and engines, he would ever have succeeded in the practical application of the theory; whether his engine would not have remained merely a model, useful in the laboratory to illustrate various physical laws, but of no use to industry. Boulton made over one of the most important branches of the iron trade in order to get a workable engine, and in order to do that he trained his workmen to a degree of skill and accuracy before unknown either in England or on the Continent. On the other hand, it is altogether doubtful if he would have appreciated the fact that the failure of the engine was due to numerous small defects in its parts which allowed leakage and waste, had not Watt been constantly on hand in the foundries to indicate these defects, and had he not been the one who set up the engines sold and stayed by them until they worked according to the contract. That is, Watt showed the points at which the theory failed in practice because the machine was badly made, while Wilkinson and Boulton wrestled with the intractable material, poor tools and unskilled workmen. If Watt had not had a firm conviction acquired from his success with his small models that his theory was correct, and if he had not also had the exactness developed by his work with fine tools on scientific instruments, he would probably have been unable to convince Boulton of the practicability of his engine.

In his biographies we do not get nearly enough account of the complicated interplay between theory and the manipulation of the models or the actual engines, but the fact that for years Watt himself set up the engines sold and stayed by them until they were in good working order, while during these same years he was adding the important conveniences of the throttle valve, counter, indicator and governor, as well as others less well known, shows how close the interaction must have been.

We are thus able from the available data to outline roughly three stages. We do not know whether he had any especial interest in steam before his discussions with Dr. Robison in 1759. From 1759 to 1763 there was a preliminary period of discussion, intermittent experiment, discovery of some of the laws of steam pressure, etc. This was followed by a more intense period of application introduced by the work with the Newcomen model and culminating in the image of the separate condenser, which within a day was tested in the first tiny model. This model in turn was followed almost at once by two or more larger ones, and in the course of

this close interaction between manipulation and thinking the double-acting piston was invented, and many other things were invented and tried out which did not work, such as a wooden case for the cylinder. As far as we can judge, the constructive aspect, the shooting together of relatively unconnected images into the constellation that we call the steam engine, occurred in a period of only about two months, during April and perhaps May of 1765. It had been preceded by the long practise period beginning in 1759, becoming more intense from 1763 on, and finally culminating in the invention.

Another practice period follows from 1765 to 1774, when he began his partnership with Boulton at Soho. During these years there seems to have been little addition to the theory, but all sorts of combinations of perceptions and images tried with a view to stopping the various leakages of steam and heat. These attempts however were not very successful. The larger engines made worked just well enough to keep alive the belief of Watt and Roebuck but not well enough to try to sell them. Watt's energies were much divided. He was obliged to take up surveying in order to support his family and pay the debts incurred in his experiments with the engine, and he made various minor inventions along quite different lines. During these years therefore he did little more than mark time. In other words, he was practicing with steam, becoming habituated to it, but he was not working with the intensity and concentration which Book found essential for the step up to the next level. He was on one of the learning plateaus.

When he went to Soho however, in 1774, Boulton provided the necessary stimuli for progress. In the first place, the partnership contract cleared up the financial tangles and freed Watt's mind from them. In the second place, under Boulton's urging, Watt obtained an extension of his patent rights for twenty-four years, so that he felt that he would get some financial profit from his invention. Finally, within six months Boulton began to take orders for engines and to guarantee that they would do a certain amount of work, so that Watt was under the pressure of making the engine at least as good as the contract provided for. The effect was immediate and great, as we have already seen, in one case the number of strokes being increased fourfold for one-half the previous amount of fuel. Within these years from 1774 to 1785 we get a combination of practice and invention which would be most instructive had we only the details. Watt was setting up the engines sold, instructing the engineers how to

run them, and constantly making the minor improvements already referred to. His fancy was constantly playing over the engine to note the weak places and possible improvements, and the constructive process again culminated in the patents taken out between 1780 and 1785, some of which were nearly as valuable commercially as the original one.

Had we the biographical data, there can be little doubt that we should be able within each of these larger periods to mark off sub-periods of the same kind, and to establish correlations between the condition of his health and his inventive power. Space is lacking here to detail the course of infringement of his patents, or his recognition of the social need and value of the steam engine. Suffice it to say that he had a clear consciousness of the benefit to humanity, but in reading his life one gets even more the impression that he kept at the work primarily because his instinct for handling things and seeing what would happen from all kinds of combinations was so strong. He fussed over all kinds of devices that turned out impractical and over many things unrelated to steam. One might almost say that his hands had a constant itch which nothing but work with physical things could stop and that with so much play with things the law of chance alone would ensure some useful things being discovered or made. On the other hand, the focussing of his interest upon steam seems to shows his sensitiveness of response to his environment and to this great industrial need of his day. Why steam made so strong an appeal to him we can not say. Did it typify the power of spirit over matter, of mental energy over physical inertia? Was his struggle against his own bodily weaknesses transferred to this plane? This is purely speculation, but it is at least interesting to see how the weakly boy harnessed the strongest force of modern civilization, making mere size and muscle of less account than ever before.

References

Babbage, Charles. Economy of machinery and manufactures.

Baldwin, J. Mark. Methods and processes.

—— ——. Social and ethical interpretations. New York, 1902. Pp. 606.

Book, W. F. Psychology of skill. University of Montana studies in psychology, 1908. Vol. 1.

Carnegie, Andrew. Jamee Watt. New York, Doubleday, Page & Co. Pp. 241.

Kent, E. B. Constructive interests of children. New York, Columbia University, 1903. Pp. 78.

Mach, Ernst. Die Mechanik in ihrer Entwicklung, historisch-kritisch dargestellt. Leipzig, 1912.

MESSER, A. Empfindung und Denken. Leipzig, 1908. Pp. 200.
MUEMANN, E. Intelligenz und Wille. Leipzig, 1908. Pp. 292.
MUIRHEAD, JAMES P. Life of James Watt. Appleton, 1859. Pp. 408.
—— ——. Origin and progress of the mechanical inventions of James Watt. London, Murray, 1854. 3 vols.
PIKLER, J. Die Stelle des Bewusstseins in der Natur. Leipzig. Pp. 34.
POINCARÉ, HENRI. Science et methode. Flammarion, Paris, 1908.
—— ——. Science et l'hypothese. Flammarion, Paris, n. d.
RIBOT, TH. L'imagination creatrice. Paris, 1900. Pp. 304.
RIGNANO, EUGENIO. Qu'est-ce que le raisonnement. *Scientia, Supplement*, 1913. No. 27, 30-57.
—— ——. Du raisonnement concret au raisonnement abstrait. *Ibid.*, No. 30, 43-67.
—— ——. De l'intuition à la déduction. *Ibid.*, No. 31, 129-156.
—— ——. Les formes superieures du raisonnement; le raisonnement mathématique. *Ibid.*, 1915. Nos. 39 and 40. Pp. 74.
RUTGERS, HENRY A. The psychology of efficiency. Woodworth's *Archives of Psychology*. June, 1910. Pp. 88.
RUYSSEN, TH. L'évolution psychologique du jugement. Paris, 1904. Pp. 382.
SMILES, SAMUEL. Lives of Boulton and Watt. London, Murray, 1865. Pp. 514.
WASHBURN, MARGARET F. The physiological basis of relational processes. *Psy. Bull.*, 1909. Pp. 369-378.
—— ——. The function of incipient motor processes. *Psy. Rev.*, Sept., 1914. Pp. 376-390.
WATSON, JOHN R. Behavior. Holt, New York, 1914. Pp. 439.